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A retrieval algorithm for TanSat XCO_2 observation: Retrieval experiments using GOSAT data

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This study developed a highly accurate retrieval algorithm for the column-averaged CO_2 dry-air mixing ratio (XCO_2) to be observed by TanSat, China's carbon dioxide observation satellite that will be launched in 2015. The Greenhouse Gases Observing Satellite (GOSAT) L1B spectrum was applied in retrieval experiment, and the results were validated with ground-observed measurements from the Total Column Carbon Observing Network (TCCON). At mid-latitudes, most results fell in the 1% error region, which correspond to the performance of GOSAT algorithm. The results also showed seasonal variation in XCO_2 in both hemispheres.

retrieval algorithm, satellite remote sensing, XCO_2, sources and sinks, TanSat

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There is a scientific consensus that anthropogenic CO_2 is the primary cause of global warming [1]. Carbon trading and carbon tariffs will greatly contribute to lessening CO_2 emissions, which will help to slow global warming. Measurable, reportable, and verifiable results were therefore emphasized at the World Climate Conference in Copenhagen in 2009 (15th Meeting). Recent modeling studies have indicated that a precision of 1% or better for the column-averaged CO_2 dry-air mixing ratio (XCO_2) is required to improve our current knowledge of surface CO_2 fluxes [2]. Satellite remote sensing will provide an opportunity for global, high-precision monitoring of atmospheric CO_2.

Traditional thermal infrared observations were only sensitive to atmospheric CO_2 in a region 5–8 km above the ground surface [3]. The near-infrared (NIR), however, can provide information on CO_2 in the planetary boundary layer (PBL) [4]. The Thermal and Near-Infrared Sensor for Carbon Observation (TANSO) aboard the Greenhouse Gases Observing Satellite (GOSAT) is a state-of-the-art hyperspectral Fourier transform spectrometer (FTS) that can monitor CO_2 in the NIR. It was successfully launched in January 2009 [5]. After the failure of the Orbiting Carbon Observatory (OCO) mission, the National Aeronautics and Space Administration (NASA) began to prepare the second OCO satellite (OCO-2), which is scheduled for launch in July 2014 [6].

TanSat is a carbon dioxide observation satellite funded and supported by the Ministry of Science and Technology of the People's Republic of China and the Chinese Academy of Sciences [7]. TanSat will carry two key instruments: a hyperspectral grating spectrometer for CO_2 and a wide field-of-view moderate-resolution imaging spectrometer for cloud and aerosol observations. TanSat will be launched in 2015 to monitor atmospheric CO_2 in a Sun-synchronous orbit. Three channels was used in CO2 retrieval, including CO_2 weak band (1.594–1.624 μm), CO_2 strong band (2.042–2.082 μm), and O_2 A band (0.758–0.775 μm).

A full physics retrieval algorithm was developed for TanSat XCO_2 monitoring. The theoretical basis is the optimal estimation method [8]. The XCO_2 estimation is ap-

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proached by a fitting process between the simulated and observed spectra (Figure 1). The radiative transfer in the atmosphere was simulated for each iteration. The information of CO_2 was retrieved from weak and strong band, while the aerosol and surface pressure approached mainly by O_2A band.

A vector linearized discrete ordinate radiative transfer (VLIDORT) model was introduced to simulate radiative transfer in the atmosphere [9]. The absorption coefficients are calculated by a line-by-line radiative transfer model (LBLRTM) [10] with Rayleigh scattering [11] included and a Lambertian surface assumed.

State vectors including the XCO_2 profile, water vapor profile, temperature profile, surface albedo, and wavenumber shift are retrieved simultaneously. The *a priori* of XCO_2 is fixed at 380 ppm. The *a priori* water vapor and temperature profiles are interpolated from European Centre for Medium-Range Weather Forecasts (ECMWF) interim 1°×1° grid data. Finally, the *a priori* surface albedo and wavenumber shifts are estimated from the spectrum.

Since the TANSO/GOSAT L1B data has a wide spectrum range, the three spectrum data corresponding to TanSat channels were selected in XCO_2 retrieval experiments. The Total Column Carbon Observing Network (TCCON) sites at Sodankyla (Finland), Karlsruhe (Germany), Lamont (USA), and Wollongong (Australia) were selected for a validation study [12]. TANSO/GOSAT data from the TCCON sites with sampling centers less than 800 km and overpass times less than ±1 h were chosen to couple with the TCCON real-time observations. In this study, we focus retrieval over land and apply only GOSAT data in nadir observation mode.

The TanSat algorithm, GOSAT product [13], and Atmospheric CO_2 Observations from Space (ACOS) V2.9 product [14] are compared in Figure 2 (statistics results indicated in Table 1). At mid-latitudes (Lamont and Wollongong), most results fell in the 1% error region, and the statistic results of TanSat algorithm were similar with the GOSAT and ACOS product. At mid- to high latitudes (Sodankyla and Karsruhe), the error in the TanSat algorithm was slightly larger than that in the GOSAT and ACOS V2.9 data, and a small part of the results fell outside the 1% region.

The time trends of the satellite and TCCON results are shown in Figure 3. The satellite retrieval results of all algorithms were similar to the TCCON observations, which decreased from winter to summer in the Northern Hemisphere and were relatively stable in the Southern Hemisphere.

The results of the validation study proved the practical applicability of the TanSat algorithm to real observation spectra. At mid- to high latitudes, however, the retrieval is still uncertain. The accuracy of the retrieval was influenced by not only the sampling precision of the instrument but also the theory and parameters used in the algorithm [15].

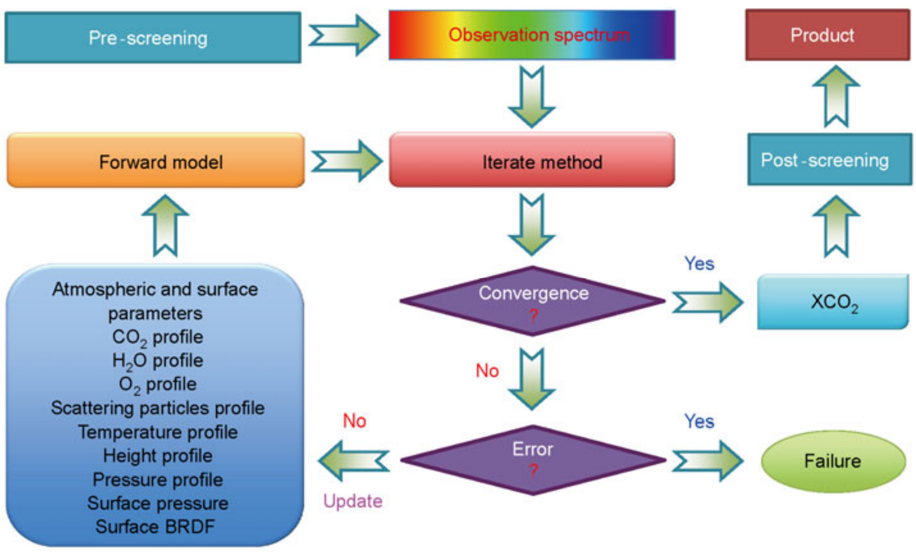

Figure 1 Flow chart of the XCO_2 retrieval algorithm.

Table 1 The bias and standard deviation (SD) of retrieval result in 4 stations

	Sodankyla		Karlsruhe		Lamont		Wollongong	
	Bias (ppm)	SD	Bias (ppm)	SD	Bias (ppm)	SD	Bias (ppm)	SD
GOSAT L2B	−1.17	3.95	−2.10	2.52	−3.06	3.98	−2.86	3.94
ACOS V2.9	2.62	3.45	−0.81	1.83	0.08	1.65	2.52	2.78
TanSat algorithm	−3.13	4.48	−2.93	3.74	−0.08	2.30	−1.53	2.26

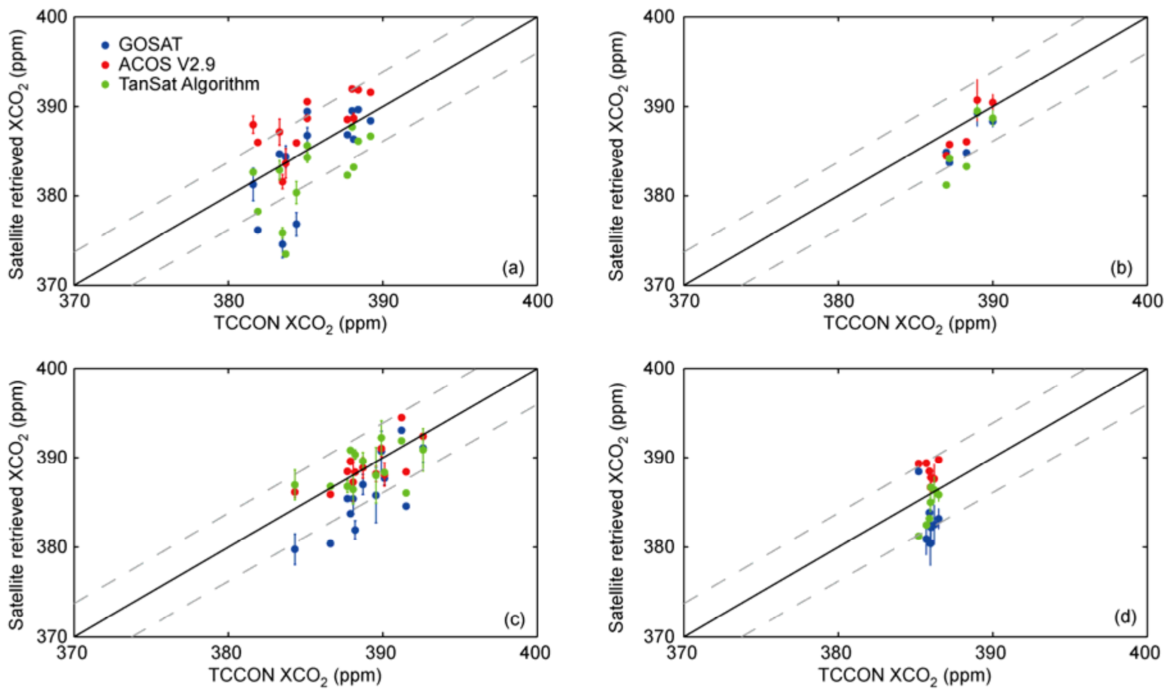

Figure 2 Scatter diagram of retrieval results in (a) Sodankyla (67.37°N, 26.63°E), (b) Karlsruhe (49.10°N, 8.44°E), (c) Lamont (36.60°N, 97.49°E), and (d) Wollongong (34.41°N, 150.88°E). Blue, red, and green represent the daily average TANSO/GOSAT L2B, ACOS V2.9, and TanSat retrieved XCO_2. The black line is 1:1 for the TCCON-observed and retrieved XCO_2, and the gray line shows the $\pm 1\%$ region. The bias and standard deviation are shown in the lower right corner of each figure. The longitude and latitude of each site are shown in the title of each figure.

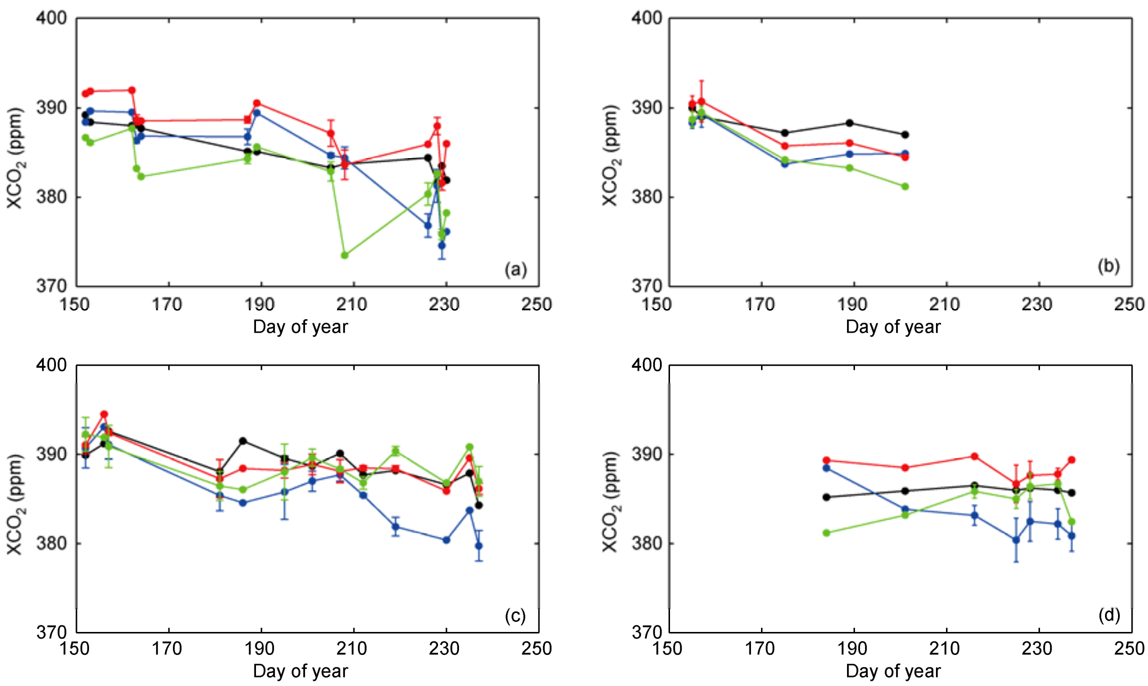

Figure 3 Time variation in daily average observation results at (a) Sodankyla, (b) Karlsruhe, (c) Lamont, and (d) Wollongong. Black, blue, red, and green represent TCCON, TANSO/GOSAT L2B, ACOS V2.9, and TanSat XCO_2 observations. The longitude and latitude of each site is shown in the title of each figure.

Development of a highly accurate XCO_2 retrieval algorithm is a challenging scientific and technological issue that requires further study.

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